NASA-TM-75885 19810012782

NASA TECHNICAL TRANSLATION

NASA TM-75885

AN EXPERIMENTAL INVESTIGATION ON THE SUBCRITICAL INSTABILITY IN PLANE POISEUILLE FLOW

Nishioka, T.; Honda, S.; and Kamibayashi, S.

Translation of "Heimen Poazuiyu Ryu ni Okeru Subcritical Instability no Jikkenteki Kenkyu," Unknown Source: pp 55-62.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. DECEMBER 1980

STANDARD TITLE PAGE

1. Report No. NASA TM-75885	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle AN EXPERIMENTAL INVESTIGATION ON THE SUB-CRITICAL INSTABILITY IN PLANE POISEUILLE FLOW		5. Report Date December, 1980 6. Performing Organization Code
7. Author(s) Nishioka, T.; Honda, S.; and Kamibayashi, S.		8. Performing Organization Report No. 10. Work Unit No.
9. Performing Organization Name and Address Leo Kanner Associates, Redwood City, California, 94063		11. Contract or Grant No. NASW-3199 13. Type of Report and Period Covered Translation
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546		14. Sponsoring Agency Code

15. Supplementary Notes

Translation of "Heimen Poazuiyu Ryu ni Okeru Subcritical Instability no Jikkenteki Kenkyu", Unknown Source: pp 55-62

16. Abstract

The relationship between the three-dimensional properties of the fundamental flow of a plane Poieseuille flow and subcritical stability was studied. An S-T wave was introducted into the flow and the three-dimensional development of the wave observed.

17. Key Words (Selected by Author(s))	18. Distribution Statement Unclassified-Unlimited

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages	22. Price

AN EXPERIMENTAL INVESTIGATION ON THE SUBCRITICAL INSTABILITY IN PLANE POISEUILLE FLOW

Nishioka, T.; Honda, S.; and Kamibayashi, S.

1. Introduction

This is a continuation of the experiments concerning stability and transition in plane Poiseuille flow. As the first experiments showed [1], when a certain threshold is crossed, there is spatial amplification even with the T-S wave which is damped at the time of microamplitude. This subcritical instability is clearly a nonlinear phenomenon. However, in Blasius flow experiments [2, 3, 4], it appeared that the effects of nonlinearity caused amplification of the three-dimensional properties and the formation of a peak-vally structure. When this is considered, the very interesting question of what connection does subcritical instability have with the three-dimensional properties of the flow comes up. In this investigation the focus is on "the aspect of the three-dimensional development of the T-S wave". /55*

2. Experimental Apparatus

Figure 1 is a diagram of the channel flow apparatus. The length is 6 m, the cross section width is 40 cm, height 2h is 1.46 cm and the aspect ratio of the cross section is 27.4. The materials are the same as used in the first experiments, except that the damping screen just before constriction was changed. This was done to make the fundamental flow more three-dimensional than it was in the first experiments. At the measuring position where a slit was made for the insertion of the heat ray probe, the flow was found to be sufficiently developed and the turbulence was 0.05%. In the coordinate system, the x axis is downstream from the mouth of the channel, the y axis downward from the depth direction center and as shown in the figure, the z axis takes the span direction. The oscillation ribbon for the introduction of the T-S wave is in the place where x = 430 cm, attached at a height of approximately 0.8 mm from the wall (lower wall). The amplitude of the ribbon and the frequency could be freely changed as desired by adjusting the current. All of the measuring was done at the z direction slit position 35 cm downstream from the ribbon. Thus, the x position of the heat ray probe was fixed. By varying the ribbon current the various states of amplification of the T-S wave could be observed. The probe was made by combining 2 I shapes, and the $y \lessgtr 0$ flow could be observed constantly.

---

* Numbers in the margin indicate pagination in the foreign text.

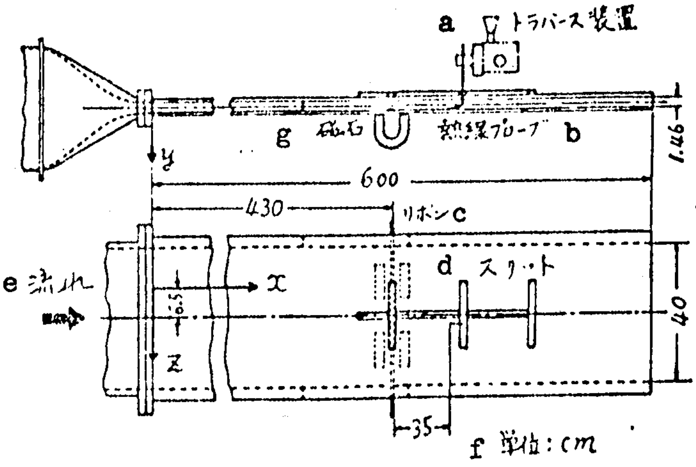

Fig. 1. Channel apparatus and coordinates

Key: a. traverse apparatus
b. heat ray probe
c. ribbon
d. slit
e. flow
f. units
g. magnet

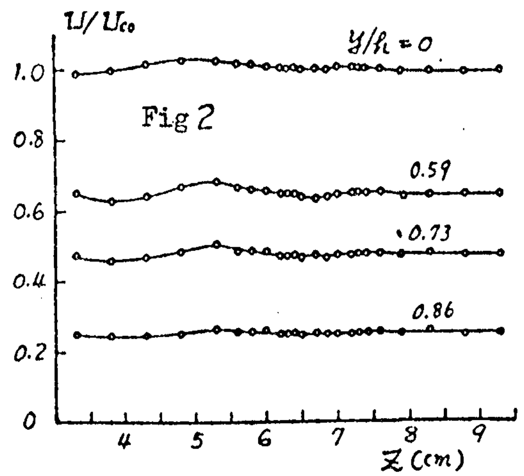

Figure 2.

3. Experimental Results and Comments /56*

Stated in terms of the central velocity Vc and the Reynolds number based on 1/2 the channel height h (=7.3 mm), the critical Reynolds number according to the linear stability theory is 5771 [5]. This was confirmed in the previous experiments. In the present experiment the main subject is subcritical instability and the Reynolds number is 5000. The frequency of the T-S wave is 72 Hz.

As shown in figure 2, the fundamental flow has made an almost periodic change in the span direction and the wave length is 2.6 - 2.7 cm. The amount of change in velocity is 5% of the very high central velocity (Vco is the value where z = 6.5cm).[1] As in figure 3, when we examine the relationship between V/Vc and y/h the y distribution describes a parabola. In figure 4, the y distribution of the amplitude (effective value u') and phase for the T-S wave at the time of microamplitude is compared with the results calculated according to Ito's [3] linear theory and agreement is good. Effective value u' takes the maximum value u'_m near the

---

[1] The z direction distribution of V (fundamental flow) measured at the z direction slit at the position of the ribbon is the same as in figure 2. Consequently, for the fundamental flow, $\partial/\partial z \doteqdot 0$.

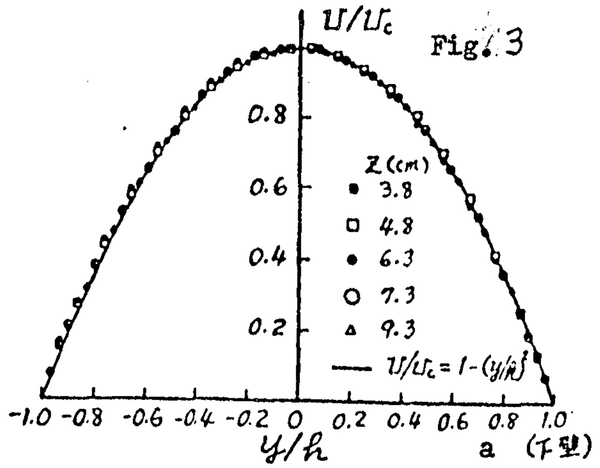

Figure 3.

Key: a. lower wall

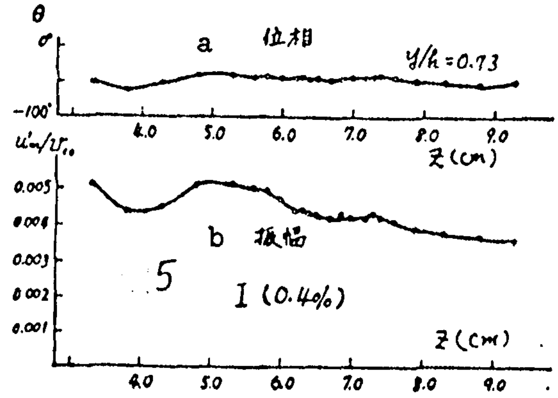

Figure 5.

Key: a. phase
b. amplitude

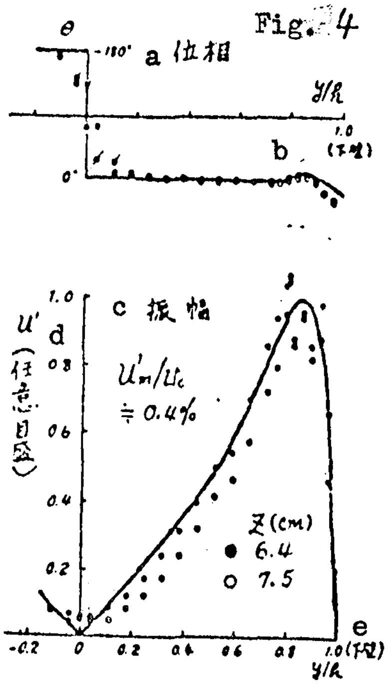

Figure 4

Key: a. phase
b. lower wall
c. amplitude
d. arbitrary scale
e. lower wall

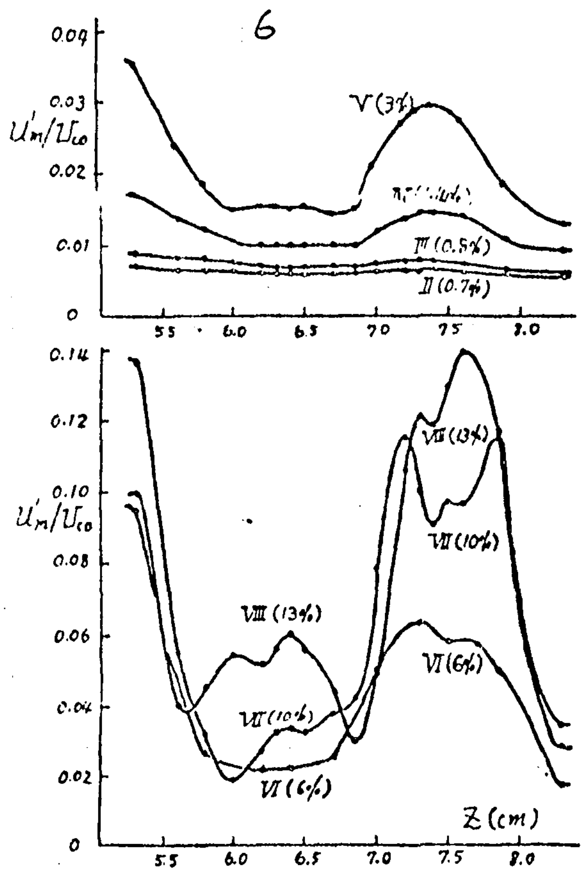

Figure 6

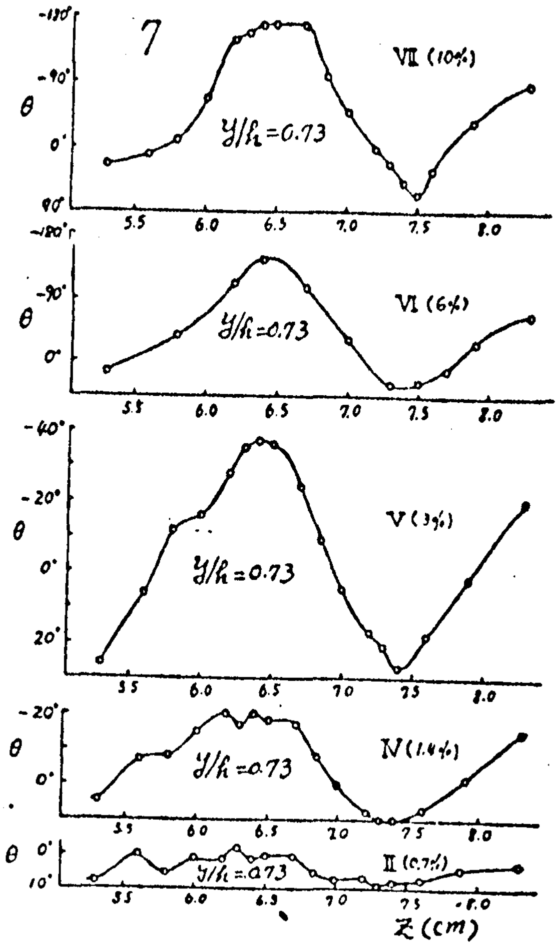

Figure 7.

wall. The phase shifts 180° at central y/h=0, is flat until near y/h = 0.75 and changes slightly near the wall. The state of the fluctuation during the change of z direction can be seen in figure 5 which shows the phase at y/h= 0.73 and the z direction distribution of u'_m. This is based on the same y distribution data as in figure 4. When figures 2 and 5 are compared, it is seen that the maximum and minimum positions of the z direction distribution of V, u'_m, and Θ (phase) are in mutual agreement. This clearly shows that the three-dimensional properties of the fundamental flow induce three-dimensional properties in the fluctuation. In order to find out how these three-dimensional properties change with an increase of the amplitude (u'_m), the y distribution of u' and Θ were minutely measured at various values of ribbon current. The z distributions of the phase Θ when u'_m and y/h = 0.73 are described from this y distribution data (recorded on x-y recorder) in figures 6 and 7. Figure 6 clearly shows the peak-valley formation process when the three-dimensional properties are amplified. z = 7.5 cm is a peak and z = 6.4 cm is a valley. In the figure the state of the flow are given the roman numeral designations II (0.7%), III (0.8%), ... The values of u'_m/Vco at peak position z = 7.5 cm are inside ( ). As shown in figure 5, the flow at the 0.4% state of microamplitude is called I (0.4%). As we can see in figure 7, the valley phase compared with that of the peak greatly lags with the increase in amplitude as indicated by II (0.7%), IV (1.4%) and V (3%). The high frequencies become conspicuous with the increase of u'_m. The phase shown in figure 7 is that of the fundamental flow at 72 Hz. For the phase the "advance" is depicted as if corresponding to the regualr direction, but the point of origin Θ = 0 is arbitrary not only in figure 7, but in all the figures. Consequently, the "differences" are always correctly expressed, but the absolute value of the phase has no significance. /57

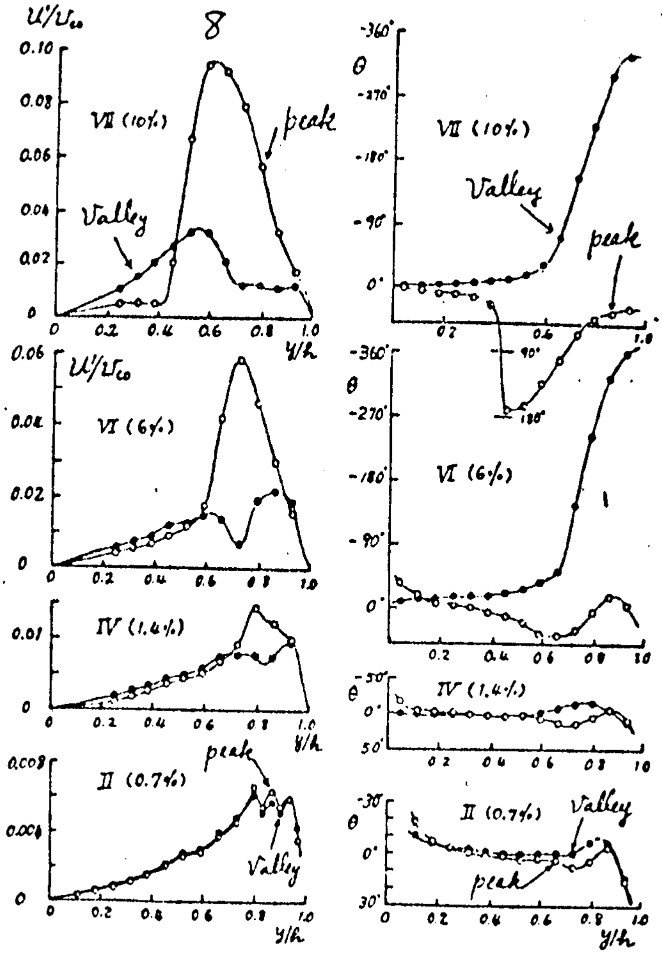

Figure 8.

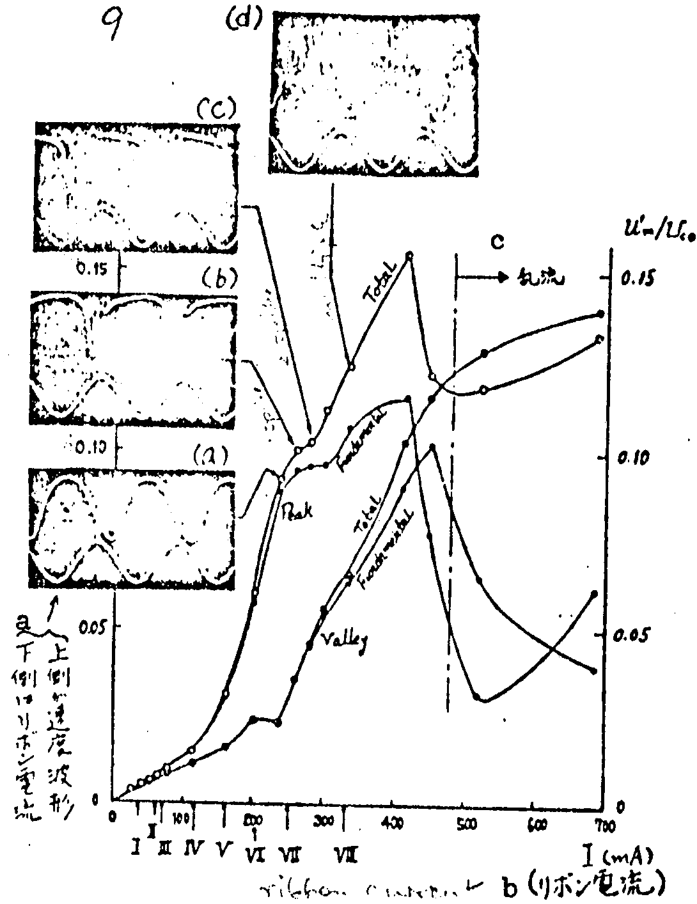

Figure 9.

Key: a. The upper side is the ribbon current and the lower side is the velocity wave form.
b. ribbon current
c. turbulent current

Figure 8 compares the y distributuon of u' and ⊖ of valley position (z = 7.5 cm, ●) with peak position (z = 7.5 cm, O) for the states II -VII based on the previously mentioned x-y recording. The u' and ⊖ distributions of state II (0.7%) are the same as those of state I (0.4%) (fig. 4), and there is almost no difference in distribution for the valley and peak positions. In state IV (1.4%) the difference is very clear, in that the peak-valley bifurcation has already occurred. The difference in values for the peak and valley of u'_m gradually starts to become very much greater with the increase in amplitude. The characteristics of the change in distribution at this time are that in the case of the peak, the y coordinates of u'_m move to the center (y=0) while the corresponding y coordinates in the valley become concave. The characteristics of the change in the y distribution of the phase are that the phase near the wall "advances" in the peak and "lags" in the valley compared with the center, and this process

accelerates greatly with the increase of u'_m. As we can see from the distributions of states VI (6%) and VII (10%), the lag in the valley reaches nearly 2π. For the valley, also, when state VII is reached, a 180° jump appears in the vicinity of $y/h = 0.4$. This corresponds to the spike wave form in photograph (b) of figure 9. As we can see /59
from this, state VII is where the process of laminar flow collapse begins. Figure 9 is a plot of u'_m (total and fundamental at 72 Hz) for the peak and valley as opposed to ribbon current I. This shows the process of the flow until it reaches the turbulent stage. It is worth noting that this is very similar to figure 4 of Klebanoff et al. [2]. The cross axis I appears very similar to x. In fact, when considered in the non-linear field, there are no objections to this. Near the point of origin $u'_m \propto I$. This is linear behavior and in the present case signifies spatial attenuation. Spatial amplification increases from when du'_m/dI are linear, but this begins to take place between II - IV, and moreover, the peak-valley branching begins at almost the same time. As was noted before, this is an extremely interesting point and will be taken up in detail later. After the branching very great spatial amplification occurs in the peak and when the process of collapse begins, there is a sequence of single spike stage (photograph b), double spike stage (photograph c) and triple spike stage (photograph d) in which there is transition to the turbulent stage along with the generation of high frequency fluctuation.

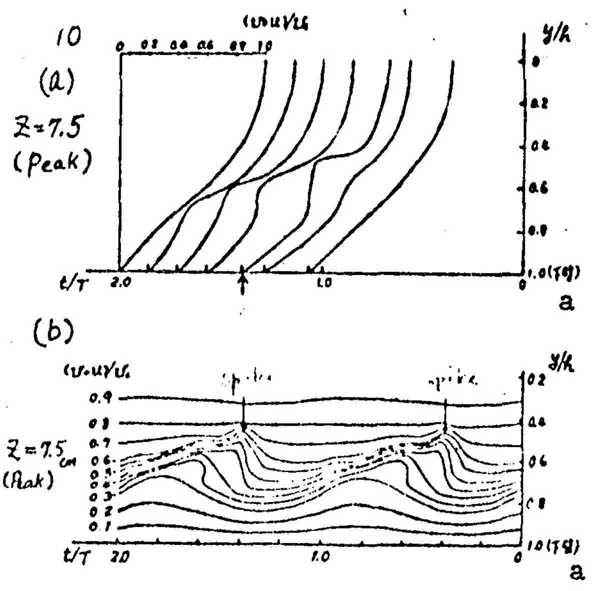

Figure 10.

Key: a. lower wall

Figures 10 and 11 illustrate the flow of the single spike stage (VI) with the instantaneous distributions taken from several photographs. Figure 10 (a) is the y distribution of the instantaneous velocity at each time of peak position (the arrow on the cross axis indicates the time when the spike was lowest, and T is the 1/72 sec. cycle). Figure 10 (b) is the uniform velocity line in the t/T - y surface. These are very similar to figure 6 (Blasius flow) which was drawn by Tani [6] on the basis of measurements taken from reference [4]. Figure 11 shows the uniform velocity lines inside the t/T - z surface. In (a) $y/h = 0.86$ and in (b) $y/h = 0.73$. A noteworthy point is that the uniform

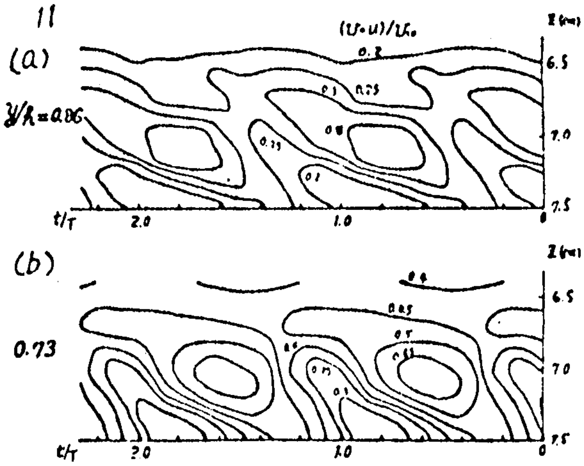

Figure 11.

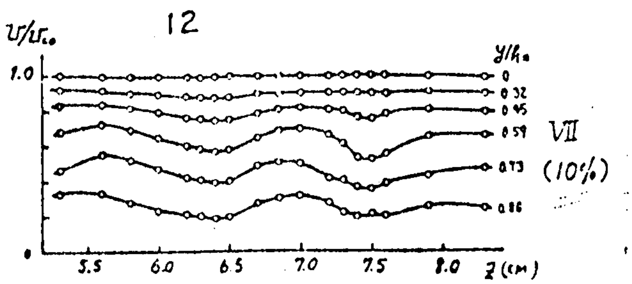

Figure 12

velocity lines where (V = u))Vco = 0.2 and 0.25 in (a) and (V = u)/Vco = 0.3, 0.35 and 0.4 in (b) resemble the shapes of turbulent spots. Figure 12 is the z /60 direction distribution of the uniform velocity of the single spike stage. There is an indentation in both the peak and valley positions, and as we can see from figure 2, the z direction distortion wave length is 1/2 of the original. This wave length remains the same as the original until state V is reached (see figure 9). Near the wall there is a tendency to be concave at the peak and to swell at the valley, but from state VI, as can be seen from figure 12 the valley indentation gradually becomes conspicuous. This is just exactly the same as the observations by Klebanoff et al [2] concerning the Blasius flow. Thus, the development process after the peak-valley bifurcation is the same as in the case of Blasius flow. It is as if a "transition orbit" were entered which leads to sudden laminar flow collapse and turbulence.

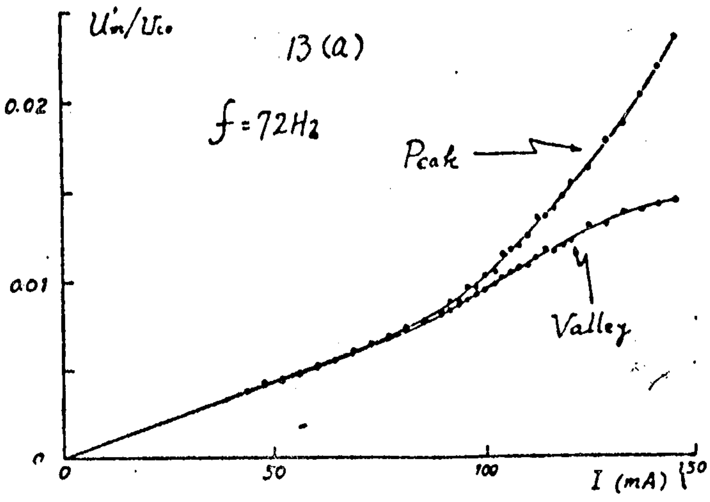

Figure 13 (a)

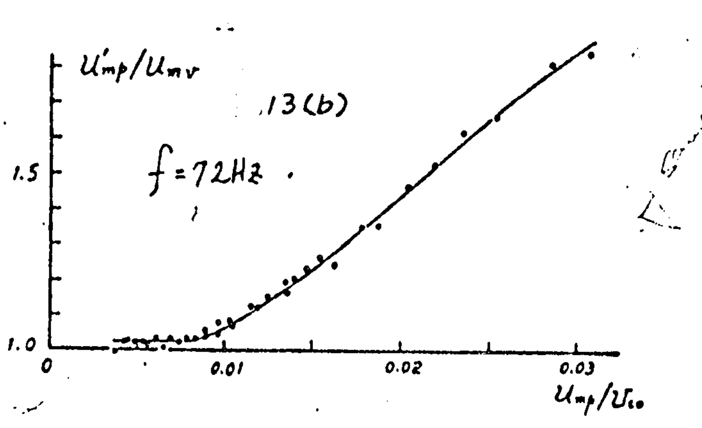

Figure 13 (b)

Next, let us look at in detail the state before and after the peak-valley bifurcation. In order to do this, the y distribution of u' and the ribbon current were altered a little at a time and measurements made. In addition to this, a recording was made in the x-y recorder while comparing the peak and valley positions. On the basis of this recording u'_m/Vco was plotted against ribbon current I as shown in figure 13 (a). In 13 (b) the ratio of u'_m at the peak and valley positions at times of identical ribbon current, i.e. u'_{mp}/u'_{mv} is shown versus u_{mp}/Vco. When both figures are compared, we see that spatial amplification (subcritical instability) begins at almost the same /61
time as peak-valley bifurcation. In this case, from figure 13 (b), for the threshold, $u'_{mp}/Vco = 0.8\%$. Based on experimental results concerning Blasius flow [2], Tani [7] suggests that the threshold amplitude is atthe peak-valley bifurcation and figure 13 (a) and (b) support this. The same kind of measurements were conducted for f = 42, 47, 52, 55, 57, 62, 67, 77, 82, and 88 Hz. Since this experiment was conducted on a different day, the viscosity was different. Consequently, the raw value of Vco was different (of course, the Reynolds number was 5000). The results are shown in figure 14 adjusted to the same form as in figure 13 (b). In order to keep the figure from being difficult to read, the results for 55 Hz are not shown. The variation in u'_{mp}/u'_{mv} accompanying the increase in u'_{mp}/Vco was the same qualitatively for all frequencies. In all cases a peak-valley bifurcation appeared at the boundary of a certain threshold. In figure 15 the black dots show this threshold $(u'_{mp}/Vco)_{th}$ plotted against dimensionless frequency $\beta \equiv 2\pi fh/Vco$. The white dots show the results of the previous experiment [1], and are from observation of the ebb and flow of fluctuation in the direction of flow (along the x direction slit). The solid line shows the results of calculations made according to Ito's [8] two-dimensional nonlinearty theory. Qualitatively, at $\beta > 0.25$ the results of this experiment and the previous one are identical, but differ at $\beta < 0.25$. The interesting thing about this is the reversal of peak and valley at the boundary $\beta = 0.25$ as shown in figure 16. For example, z = 7.5 cm is a peak when f = 72 Hz, but at f = 42 Hz there is a reversal and a valley appears. Concerning this reversal, it is believed that a

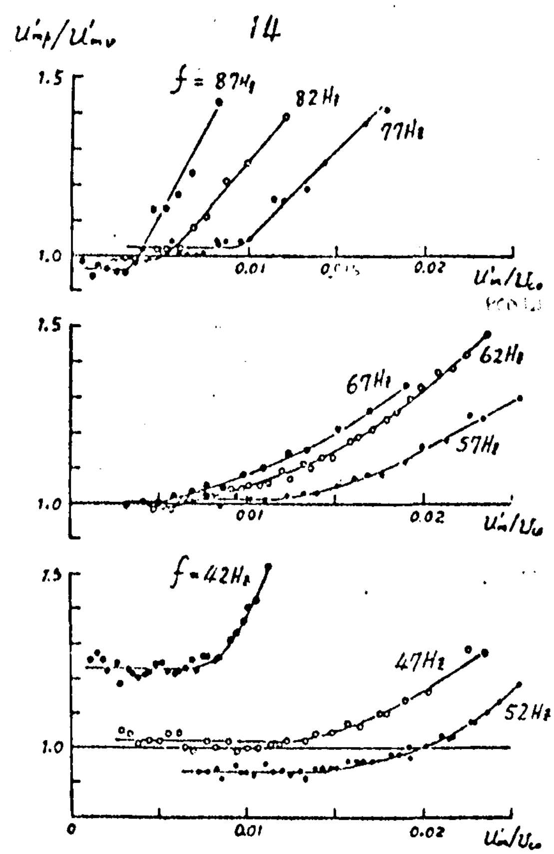

Figure 14.

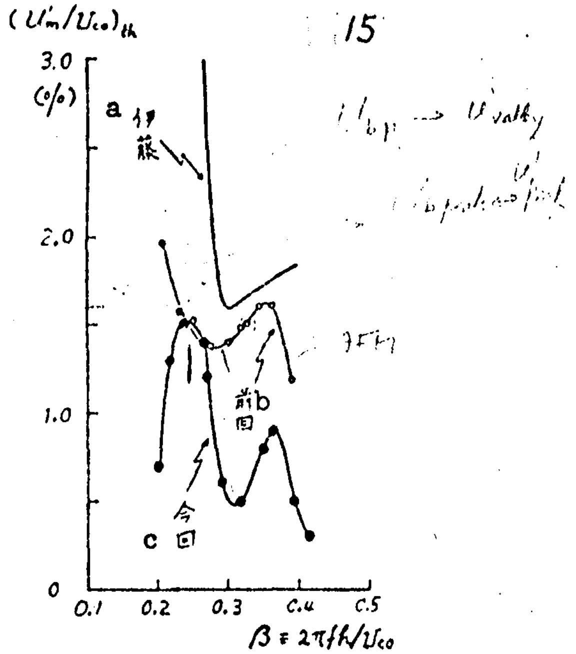

Figure 15

Key: a. Ito
b. previous experiment
c. this experiment

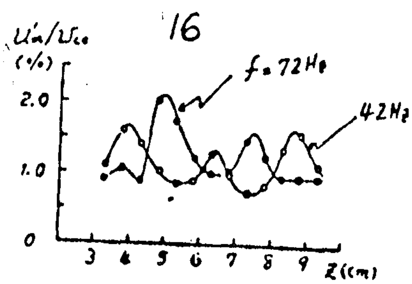

Figure 16.

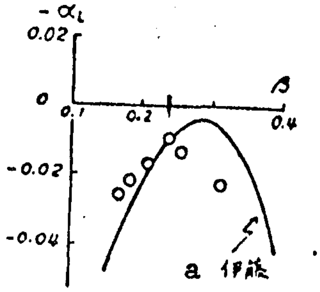

Figure 17

Key: a. Ito

pure two-dimensional explanation can be given for it, just as in the case of Blasius flow [2]. In figure 17 the experimental results on the spatial amplification rate $(-\alpha L)$ ($R = 5300$) [1], and the calculated results ($R = 5000$) [5] are compared. By calculation the value of the minimum attenuation rate of β is 0.28 and the experimental results give 0.25. A z direction change in Vc results in z direction change in β and $-\alpha L$, and a u'_m maximum is created in the linear field corresponding to the minimum of $-\alpha L$. Consequently, there is a peak at the maximum value of Vc (for example at z = 7.5 cm) when the frequency is within the range of $\partial(-\alpha L)\partial\beta < 0$ and conversely, a valley when the frequency is in the range of $\partial(-\alpha L)\partial\beta > 0$. The experimental results confirm this exactly.

As was related above concerning the /62
flow in a linear field, from a purely two-dimensional point of view, the extent of the influence of the T-S wave on distortion of the fundamental flow strongly depends on the dimensionless frequency β. This means that the influence becomes greater as the β under consideration becomes greater. Consequently, it can be assumed that the peak-valley bifurcation also will come sooner. The $(u'_m/V_{co})_{th} - \beta$ curve obtained in this experiment (as shown in figure 15) is in the range of $\beta < 0.24$ and $\beta > 0.38$, and the downward turn is thought to be due to this influence. That is to say, it can be assumed that there was probably

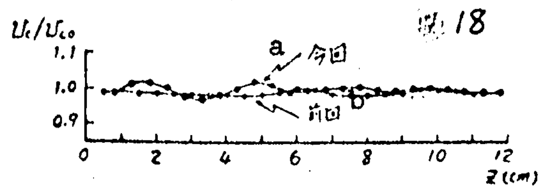

Figure 18.

Key: a. this experiment
b. previous experiment

a downward turn at $\beta < 0.2$. Of course, the distortion of the fundamental flow is also a problem. The z direction distribution of the Vc of the flow in the previous experiments and these experiments are compared in figure 18, and it is clear that distortion was greater in these experiments. One of the probable reasons for this is that in comparing the two-dimensional calculations and the results of this experiment, the threshold was smaller in the experiment.

We are concerned about the problem of how the wave length of the three-dimensional properties (of the fundamental flow), the secondary flow (of the fundamental flow), etc. are intertwined, but nothing in general can be said about this from these experiments.

Calculated results concerning nonlinear stability in considering three-dimensional disturbance have been published, but unfortunately, they are not of the sort which can be directly compared with the results of these experiments.

4. Summary

These experiments concern an R = 5000 plane Poiseuille flow in which the central velocity makes an almost cyclic change at 5% (peak-to-peak) amplitude. We attempted to find out what kind of connection the three-dimensional properties of the fundamental flow have with subcritical instability. The results are as follows:

(1) The T-S wave has three-dimensional properties which are synchronous with the fundamental flow, but there is damping at microamplitude.

(2) When the amplitude reaches a certain threshold, subcritical instability and peak-valley bifurcation occur simultaneously and a peak-valley structure is formed.

(3) This threshold depends to a great extent on the frequency.

(4) After the peak-valley bifurcation there is a transition to a turbulent flow by the process of laminar flow collapse indentical to that in Blasius flow.

REFERENCES

1. Nishioka, M., S. Iida, and Y. Ichikawa, J. Fluid Mech. 72, 731 (1975); and The Fifth Symposium on Turbulent Flow.

2. Klebaneff, P.S., K.D. Tidstrom, and L.M. Sargent, J. Fluid Mech., 12, 34 (1962).

3. Tani, I., and H. Komoda, J. Aeron. Sci 29, 440 (1962)

4. Kovasjnay, L.S.G., H. Komoda, and B.R. Vasudeva, Pro. 1962 Heat Transfer and Fluid Mech. Inst., 1 (1962).

5. Itoh, N., Trans. Japan Soc. Aero. Space Sci., 17, 65 (1974).

6. Tani, I., Annual Review of Fluid Mechanics, 1, 169 (1969)

7. Tani, I, ZAMM, 53, T25 (1973).

8. Itoh, N., Trans. Japan Soc. Aero. Space Sci., 17, 160 (1974).